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US Army Corps
of Engineers
Waterways Experiment
Station

Assessing Workability Complaints in Mass Concrete Construction

by Billy D. Neeley
Structures Laboratory

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Final report

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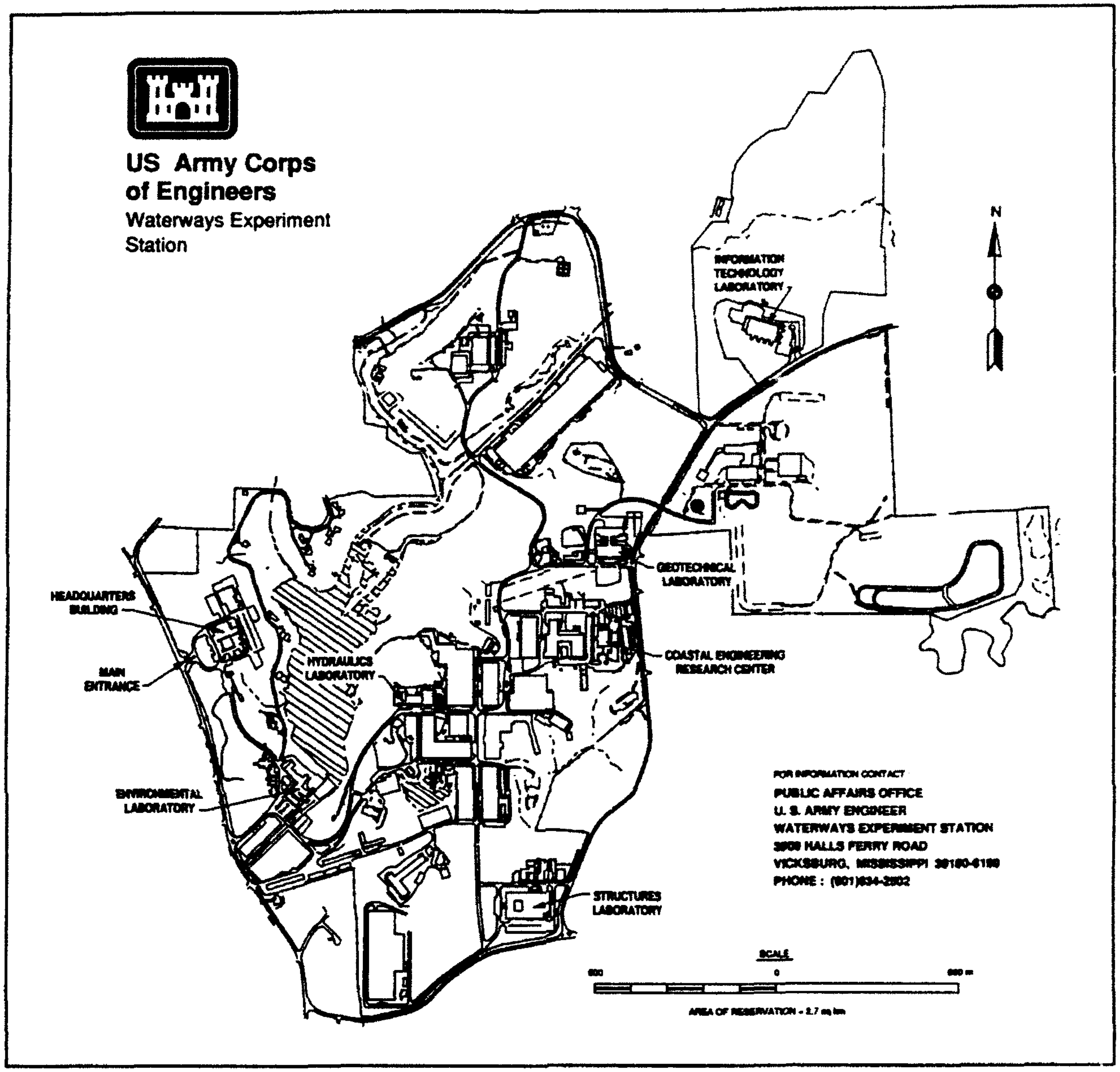

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Contents

Preface

This report was prepared by the Structures Laboratory (SL), U.S. Army Engineer Waterways Experiment Station (WES), under the sponsorship of Headquarters, US Army Corps of Engineers, as a part of Civil Works Investigation Studies Work Unit 32768, "Workability of Mass Concrete."

The study was conducted under the general supervision of Messrs. Bryant Mather, Director, SL, and James T. Ballard, Assistant Director, SL. Direct supervision was provided by Messrs. Kenneth L. Saucier, Chief, Concrete Technology Division (CTD), and Steven A. Ragan, Chief, Engineering Mechanics Branch (EMB), CTD. Mr. Billy D. Neeley, EMB, was the Principal Investigator and prepared this report. The author acknowledges the assistance of Mr. Willie E. McDonald, EMB, and the many Corps of Engineers district and division and contractor staff members who participated in the survey described in this report.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Leonard G. Hassell, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
feet	0.3048	metre
inches	25.4	*millimetres*

1 Introduction

Background

A large percentage of concrete used by the U.S. Army Corps of Engineers (CE) to construct Civil Works structures is mass concrete which is proportioned by the division laboratories in accordance with the American Concrete Institute (ACI) Standard 211.1 (ACI 1989) (CRD-C 99).[1] Recently, a number of contractor complaints have been made at CE projects regarding poor workability of mass concrete. In some instances, these complaints have been followed by actual production delay claims. Although the problems associated with the concrete workability generally appear to be related more to the contractor's selection of materials, placing operations, or lack of adequate Contractor Quality Control (CQC) than the Government's mixture proportions, it is often difficult for the Government to be certain that the mixture itself is not at fault. Civil Works Investigation Studies Work Unit No. 32768, "Workability of Mass Concrete," was initiated to address some of the problems related to the workability of mass concrete.

Purpose

The purposes of this study were to (a) determine the extent of mass concrete workability complaints throughout the CE as well as the purported causes of these problems; (b) categorize the causes into broad areas such as materials, mixture proportions, transporting and placing, and consolidation; (c) examine the problems in each category to determine the research needed to address each problem; and (d) make recommendations that will enable CE division laboratory and field staff members to predict and address concrete workability problems in a more timely and satisfactory manner.

[1] The CRD-C equivalent in parentheses is from the *Handbook for concrete and cement*, U.S. Army Engineer Waterways Experiment Station, 1949, Vicksburg, MS.

Scope

The initial phase of this study was to obtain information from CE division and district staff members having recent experience with mass concrete construction. Their input was solicited to describe workability complaints as well as the purported causes of the problems. A survey form (Appendix A) was designed to identify potential problems in five areas that could lead to workability problems or the perception of workability problems. The five areas were (a) materials, (b) mixture proportions, (c) transporting and placing, (d) consolidation, and (e) overall considerations. In response to each question, the respondent was asked to indicate the frequency that problems occurred in the area under scrutiny. The response choices were (a) often, (b) occasionally, or (c) seldom. Space was also provided to allow a detailed description of significant problems and, if known, the source of the problem and the corrective action taken. The results of the survey were used to aid development of needed research to address significant problem areas.

Thirty-five survey forms were sent out. Engineering, construction, materials, and field staff members working under the supervision of the following divisions participated in the survey:

Lower Mississippi Valley Division
Missouri River Division
North Atlantic Division
North Pacific Division
Ohio River Division
South Atlantic Division
Southwestern Division

Some division staff members duplicated the forms and sent them to additional individuals.

2 Survey Results

Response

Thirty-four survey forms were completed by CE staff members and returned. Some respondents indicated their appreciation in being asked to provide input that would ultimately give guidance in the development of research designed to aid them in ensuring that structures built by the CE are of high quality. In addition to the responses by CE staff members, five survey forms were completed by contractor staff members at the request of the U.S. Army Engineer Division, Ohio River (ORD). It was encouraging that five of the problem areas identified by CE staff members were also identified by contractor staff members.

The 34 forms returned by the CE were evaluated separately (Table 1) from the 5 forms returned by ORD contractor's staff (Table 2). As indicated on page 4, the choices regarding each of the 84 possible alleged bases for complaints were limited to three possible answers "often," "occasionally," and "seldom." There was no opportunity for a respondent to reply that he or she had no experience with the issue involved or that he or she had not received or, in the case of contractors, made a complaint on that basis. Hence, for all 84 items, the responses from the Corps of Engineers (Table 1) add up along a line to 34 (100%), unless a respondent left an item blank, or from contractors (Table 2) to 5 (100%), unless a respondent left an item blank. The number of responses to each area listed in the survey are given in Appendix B for CE and Appendix C for contractors.

Evaluation Criteria

As expected, a diversity of responses was received. Criteria were needed to evaluate the results of the survey. The scope of the study would allow for only a limited number of areas to be addressed in depth. Therefore, it was necessary to select the areas where complaints occurred most frequently for further investigation. This selection was based on the following criteria:

a. The frequency that complaints often occur exceeds 33 percent.

b. The frequency that complaints occasionally occur exceeds 67 percent.

c. The frequency that complaints seldom occur is less than 33 percent (which is to say that 67 percent or more of the time complaints occurred either often or occasionally).

An area was identified as a source of significant problems if the responses met either of these three criteria.

The frequency of each response by the CE and contractors is given in Tables 1 and 2, respectively. The areas which meet one or more of the selection criteria are identified in bold print. Those selected areas are listed again in Table 3. The areas are also marked as being identified by the CE or contractors.

Discussion

CE responses

Using the evaluation criteria stated in paragraph 6, twenty-seven complaint areas were identified by CE staff member (Table 3). The numbers of identified complaint areas in each major area were as follows:

a. Materials	2
b. Mixture proportions	5
c. Transporting and placing	6
d. Consolidation	7
e. General	7

The survey indicated that aggregates were frequently handled and stored improperly. Improper handling can result in segregation which leads to poorly graded aggregates in the concrete mixture and then to complaints about concrete workability. Everyone concerned should be familiar with proper handling and storage techniques to prevent segregation and contamination of aggregates. Aggregates are frequently out of specification on one or more sieve sizes. Since mass concrete is sensitive to a change in aggregate gradings, problems with concrete workability often result in complaints when aggregates are frequently out of specification. Steps should be taken to correct deficiencies in aggregate gradings without delay and to ensure that the aggregates meet specified gradings consistently.

The survey indicated that concrete mixture proportions frequently require adjustments when taken from the laboratory to the field to correct deficiencies in the slump and air content. These adjustments are usually necessary because of a change in aggregate grading. An adjustment of the water content to increase or decrease the slump should be made only after it has been determined that all aggregates meet specification limits for grading and that the combined aggregate grading is as near the optimum as practical. Precautions should be taken to ensure that compressive strength requirements are unaffected by adjustments to the water content. Water-cement ratios (w/c) should be held constant when there is any increase in water content unless compressive strengths are sufficiently high to permit an increase in the w/c or, if applicable, durability requirements permit an increase in the w/c. The w/c should remain constant with any decrease in water content provided the reduction in cement does not create an excessively harsh mixture. After it has been determined that transporting procedures are correct and are not affecting air content of the concrete, the dosage of air-entraining admixtures should be adjusted so as to maintain the air content within job specifications.

Improper placement procedures can result in segregation. Numerous transfer points in a conveyor system can cause segregation. Excessive freefall in a noncontinuous discharge from conveyor systems can also cause segregation. Concrete should be contained in a chute to a point less than 5 ft[1] above the placement. Fresh concrete should not be allowed to fall through reinforcing steel which causes segregation. Extreme care must be taken when beginning a placement on top of a previous lift of hardened concrete. Segregation can occur as large aggregate particles hit the hard surface and bounce away from the main body of fresh concrete. In addition, the stream of fresh concrete should be directed straight into corners to prevent the opportunity for segregated large aggregate particles to collect and form rock pockets.

The survey indicated that concrete conveyors are prone to frequent breakdown. Equipment downtime can have a negative impact upon placement schedules as well as causing a loss of any concrete on the system at the time of the equipment failure. Every effort should be made to ensure that conveyors are in good working order prior to a concrete placement and that regularly scheduled maintenance is performed to reduce the chances of a failure occurring during a concrete placement.

The survey indicated that slump loss frequently occurred when concrete was transported in revolving drum trucks or pumped. Concrete should not be allowed to stay in revolving drum trucks for extended periods of time where continued agitation may break down aggregate particles causing a slump loss. The lines in a pumping system should contain a minimum number of bends and be made up primarily of rigid pipes.

It appears that poorly maintained vibrators are frequently proposed for use in consolidating mass concrete. Use of such vibrators can give the false impression of unworkable concrete and result in poorly consolidated concrete. Only vibrators in good operating condition with proper amplitude and frequency should be used to consolidate mass concrete.

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[1] A table of factors to convert non-SI units of measurement to SI units is presented on page vi.

The survey also indicated that mass concrete is frequently vibrated improperly. Improper consolidation procedures can also give a false impression of unworkable concrete. Workers familiar with placing and consolidating structural concrete may not recognize that more mechanical effort is necessary to properly consolidate mass concrete with large aggregate and low slump than is necessary to properly consolidate structural concrete with smaller aggregate and higher slump.

Proper spacing of insertions of the vibrator and adequate duration of vibration at each insertion is essential for good consolidation. Spacing of vibrator insertions should be such that there is an overlap of the radius of action of the vibration. Once the concrete is properly consolidated in an area around the vibrator, the vibrator should be withdrawn slowly to allow the concrete to move into the hole created as the vibrator is withdrawn. Rapid withdrawal of a vibrator can leave a "posthole" in low slump mass concrete. Since mass concrete is almost always placed in courses, it is necessary that the vibrator penetrate into the previous course to ensure that the separate courses making up a lift of concrete are tied together, thus preventing course lines. The terms "course" and "lift" are defined in ACI 116R (ACI 1990). Proper vibrator positioning close to forms is essential for good consolidation and appearance of the hardened surface once the forms are removed. Vibrators should be inserted close enough to formwork so that the radius of action of the vibration extends to the forms, but the vibrator should not come in direct contact with the form. Excessive amounts of air voids and honeycombed areas frequently result due to improper consolidation. These imperfections can usually be prevented if proper placing and consolidation procedures are followed.

The survey indicated that complaints about surface defects usually result because of improper formwork, poor placement procedures, and poor consolidation procedures. Poorly sealed formwork can result in leakage of water or paste from the concrete during vibration and ultimately produce sand streaks or rock pockets. Improper alignment of forms prior to placing of concrete or failure to take corrective measures when formwork shifts out of alignment during concrete placement will result in uneven surfaces. In some cases, it may be difficult to form and place successive lifts of the structure when a preceding lift is out of alignment.

Contractor staff

Using the evaluation criteria stated in paragraph 6, eleven complaint areas were identified by contractors (Table 3). The number of identified complaint areas in each major area were as follows:

a. Materials	2
b. Mixture proportions	3
c. Transporting and placing	2

d. Consolidation 2

e. General 2

Seven of the eleven complaint areas identified by contractor staff were also identified by CE staff.

In addition to the complaints identified by the CE, the survey of contractors indicated that pozzolan frequently was not uniform or did not meet specifications or both. How failure of a pozzolan to meet specifications could result in a workability complaint is unclear. The survey also indicated that adjustments to mixture proportions may be necessary during the course of construction, usually because of a change in aggregate grading. Lastly, the survey of contractors indicated inadequate rate of delivery of concrete to the placement site with revolving drum trucks was a cause of workability complaints.

Detailed descriptions of problems

Several respondents included a detailed description of problems they had encountered and some offered possible solutions. These responses are given in Appendix B. Many of the statements reiterated conclusions drawn from the survey, such as inadequate vibration equipment, techniques, or both, and problems with conveyor breakdown and segregation of concrete on conveyors. In addition, several other items were mentioned and are summarized as follows:

a. Aggregate moisture not monitored properly.

b. Mass concrete made with manufactured sand may be excessively harsh.

c. Excessive variation of cement and fly ash can cause concrete strengths to be erratic (how this relates to workability was not stated).

d. Mass concrete mixtures are sometimes unnecessarily harsh and difficult to place and consolidate unless procedures are almost perfect.

e. 37.5-mm (1-1/2-in.) nominal maximum size aggregate (NMSA) mixtures should be proportioned to have a minimum mortar content in a manner similar to that of 75-mm (3-in.) NMSA mixtures.

f. Laboratory should check mixtures to determine the ease of consolidation before sending to field.

g. Contractors increasingly are wanting mixtures having higher slumps that are easier to place.

h. Better and quicker field adjustments to mixtures are needed.

i. Temperature control not given enough priority (how this relates to workability is not clear).

j. Reinforcing steel too congested in some areas.

k. Accumulative weigh batchers should not be used.

l. Open-top agitator bodies must be modified for 75-mm (3-in.) NMSA concrete.

m. More emphasis should be placed on field situations in PROSPECT courses.

n. Training on handling materials, transporting, placing, and consolidation concrete for contractor personnel must be considered.

3 Conclusions and Recommendations

Conclusions

Response to the survey was good. There is an interest in reducing complaints by improving the workability of mass concrete and maintaining the highest standards of quality for structures built by the CE. By their nature, mass concrete mixtures are lean and, if not properly proportioned, can be harsh. It should be recognized that laboratory conditions where mixtures are proportioned are often nearly ideal and always different from the actual field conditions. While the CE field staff members are responsible for assuring that the contractor uses materials that meet specifications and proper procedures to mix, transport, place, and consolidate, the laboratory staff who proportion mass mixtures should do so realizing that field conditions are never ideal. Mixtures should be proportioned in such a way to accommodate a reasonable amount of field variations without causing excessively harsh mixtures. The solution may be to increase the mortar content by a small enough amount to provide additional workability without causing an excessive increase in temperature rise. This scenario may now be possible with increasing amounts of cement being replaced with fly ash or other pozzolan or slag.

Attention should be given to the handling and stockpiling of aggregates. Aggregates that are out of specification for grading are frequently the cause of complaints about harsh, unworkable mass concrete mixtures. Improper aggregate moisture corrections can also result in complaints about unworkable concrete and varying strengths.

CE and contractor staff members should work together quickly to resolve problems that cause complaints about unworkable concrete. If adjustments to the concrete mixture are needed, proper adjustments should be made. Laboratory staff should be consulted if necessary. However, concrete mixtures should not be adjusted to avoid complaints if this involves accepting materials that are out of specification or improper placing, transporting, or consolidation procedures. CQC and CE staff members should quickly inform the contractor of any nonconformance and encourage compliance.

Improper consolidation of mass concrete appears to be a serious problem. Perhaps this is due to inexperience of the contractor's staff members in working with mass concrete. Improper consolidation equipment or procedures, or both, can give a false impression of unworkable concrete. Meetings with or training sessions for contractor staff, or both, prior to and during early construction about consolidation of mass concrete could help to reduce the frequency of complaints concerned with improper consolidation.

Recommendations

It is recommended that the information obtained from this survey be included in appropriate guidance documents so that CE can be alerted to specific areas where complaints are likely to develop. Reinforced with this information, CE staff members may be able to take initiatives prior to the start of a job to curtail some of the complaints that could develop in handling, transporting, placing, and consolidating.

It is recommended that a laboratory investigation be initiated to examine the feasibility of requiring a minimum mortar content in 37.5-mm (1-1/2-in.) NMSA mass concrete similar to the requirement for 75-mm (3-in.) NMSA mass concrete. This should be done while taking into consideration temperature rise considerations which may develop as mortar contents increase.

It is recommended that a laboratory investigation be initiated to examine the feasibility of requiring a paste-mortar ratio in 37.5-mm (1-1/2-in.) NMSA mass concrete and in 75-mm (3-in.) NMSA mass concrete similar to the requirement for roller-compacted concrete.

It is recommended that the feasibility of placing mass concrete at higher slumps be examined. High-range water-reducing admixtures should be evaluated to determine their effects upon fresh and hardened concrete properties.

It is recommended that the CE consider requiring meetings or training sessions for the contractors involved with consolidating mass concrete. This could be especially useful in avoiding or reducing complaints when the contractor's staff members do not have prior experience working with mass concrete.

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Table 1
Survey Results of Corps of Engineers Staff

1. PROBLEMS RELATING TO MATERIALS

A. Handling and Storage

	OFTEN %	OCCASIONALLY %	SELDOM %
(1) Cement	3	21	76
(2) Pozzolan	0	24	76
(3) Aggregates	18	70	12
(4) Admixture	9	24	67

B. Uniformity and/or Meeting Specifications

	OFTEN %	OCCASIONALLY %	SELDOM %
(1) Cement	0	27	73
(2) Pozzolan	12	35	53
(3) Aggregates	18	70	12
(4) Admixtures	0	33	67
(5) Steel reinforcement	3	9	88
(6) Curing compounds	13	31	56
(7) Joint materials	3	31	66

2. PROBLEMS RELATING TO MIXTURE PROPORTIONS

A. CE Proportioned Mixtures

	OFTEN	OCCASIONALLY	SELDOM
(1) Recommended mixture proportions require major adjustments when taken from laboratory to field	16	52	32
(a) Adjustments were necessary to correct deficiencies in:			
Slump	27	50	23
Air content	16	52	32
Segregation	4	48	48
Strength	0	29	71

Table 1 (Continued)

	% OFTEN	% OCCASIONALLY	% SELDOM
(b) Adjustments were necessary because of a change in materials from laboratory to field	6	52	42
(2) Recommended mixture proportions require major adjustments during the course of a job	7	34	59
(a) Adjustments were necessary to correct deficiencies in:			
Slump	20	53	27
Air content	20	40	40
Segregation	3	55	42
Strength	3	29	68
(b) Adjustments were necessary because of a change in these materials:			
Cement	0	39	61
Pozzolan	7	39	54
Aggregates	17	69	14
Admixtures	3	35	62

3. PROBLEMS RELATING TO TRANSPORTING AND PLACING

A. Bucket

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	6	45	49
(2) Loss of air content	9	40	51
(3) Segregation	0	45	55
(4) Delivery rate	12	62	26
(5) Breakdown of equipment	3	56	41

Table 1 (Continued)

B. Conveyor

	% OFTEN	% OCCASIONALLY	% SELDOM
(1) Slump loss	19	42	39
(2) Loss of air content	29	32	39
(3) Segregation	19	55	26
(4) Delivery rate	3	58	39
(5) Breakdown of equipment	13	74	13

C. Revolving Drum Trucks

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	16	59	25
(2) Loss of air content	9	41	50
(3) Segregation	0	28	72
(4) Delivery rate	6	56	38
(5) Breakdown of equipment	0	61	39

D. Open-Top Truck Bodies

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	11	46	43
(2) Loss of air content	4	36	60
(3) Segregation	8	62	30
(4) Delivery rate	0	34	66
(5) Breakdown of equipment	0	38	62

E. Pump

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	27	47	26
(2) Loss of air content	24	38	38

Table 1 (Continued)

	% OFTEN	% OCCASIONALLY	% SELDOM
(3) Segregation	3	40	57
(4) Delivery rate	3	47	50
(5) Breakdown of equipment	13	50	37

4. PROBLEMS RELATING TO CONSOLIDATION

A. Inadequate Vibration

	OFTEN	OCCASIONALLY	SELDOM
(1) Undersized vibrator	15	47	38
(2) Poorly maintained vibrator	35	47	18
(3) Improper spacing of insertions	59	29	12
(4) Inadequate duration of insertions	34	34	32
(5) Failure to penetrate into previous layer	41	38	21
(6) Wrong position relative to form	36	40	24
(7) Low slump	6	61	33
(8) Segregation	3	48	49
B. Overvibration			
(1) Oversized vibrator	6	18	76
(2) Improper procedures	32	21	47
(3) High slump	9	38	53
C. Resulting Imperfections			
(1) Honeycomb	32	53	15
(2) Excessive air voids	31	49	20
(3) Layer lines	15	49	36
(4) Form streaking	6	55	39

Table 1 (Concluded)

	% OFTEN	% OCCASIONALLY	% SELDOM
(5) Aggregate transparency	0	38	62
(6) Excessive form deflection	12	61	27
(7) Excessive loss of entrained air	0	27	73
(8) Cold joints	0	55	45

5. GENERAL

A. Surface Defects Appear to Result because of:

	OFTEN	OCCASIONALLY	SELDOM
(1) Design of members	3	22	75
(2) Improper formwork	13	72	15
(3) Construction conditions	6	55	39
(4) Properties of fresh concrete	3	29	68
(5) Placement procedures	34	50	16
(6) Consolidation procedures	41	50	9

B. Workability Problems Appear to Result because of:

(1) Excessive variation in concrete materials	9	53	38
(2) Poor mixture proportions	15	33	52
(3) Failure to adjust mixture proportions properly	28	41	31
(4) Improper batching/mixing equipment/procedures	9	47	44
(5) Improper transporting equipment/procedures	9	63	28
(6) Improper placing equipment/procedures	19	59	22
(7) Improper consolidation equipment/procedures	33	52	15

Table 2
Survey Results of Contractor Staff

1. PROBLEMS RELATING TO MATERIALS

A. Handling and Storage

	OFTEN %	OCCASIONALLY %	SELDOM %
(1) Cement	0	20	80
(2) Pozzolan	0	0	100
(3) Aggregates	0	60	40
(4) Admixture	0	0	100

B. Uniformity and/or Meeting Specifications

	OFTEN %	OCCASIONALLY %	SELDOM %
(1) Cement	0	0	100
(2) Pozzolan	0	80	20
(3) Aggregates	20	80	0
(4) Admixtures	0	0	100
(5) Steel reinforcement	0	0	100
(6) Curing compounds	0	0	100
(7) Joint materials	0	0	100

2. PROBLEMS RELATING TO MIXTURE PROPORTIONS

A. CE Proportioned Mixtures

	OFTEN	OCCASIONALLY	SELDOM
(1) Recommended mixture proportions require major adjustments when taken from laboratory to field	0	67	33
(a) Adjustments were necessary to correct deficiencies in:			
Slump	75	25	0
Air content	0	50	50
Segregation	0	0	100
Strength	0	0	100

Table 2 (Continued)

	% OFTEN	% OCCASIONALLY	% SELDOM
(b) Adjustments were necessary because of a change in materials from laboratory to field	0	25	75
(2) Recommended mixture proportions require major adjustments during the course of a job	25	25	50
(a) Adjustments were necessary to correct deficiencies in:			
Slump	50	50	0
Air content	0	50	50
Segregation	0	0	100
Strength	0	0	100
(b) Adjustments were necessary because of a change in these materials:			
Cement	0	0	100
Pozzolan	0	0	100
Aggregates	0	75	25
Admixtures	0	20	80

3. PROBLEMS RELATING TO TRANSPORTING AND PLACING

A. Bucket

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	0	0	100
(2) Loss of air content	0	0	100
(3) Segregation	0	25	75
(4) Delivery rate	0	20	80
(5) Breakdown of equipment	20	0	80

Table 2 (Continued)

B. Conveyor

	% OFTEN	% OCCASIONALLY	% SELDOM
(1) Slump loss	0	0	100
(2) Loss of air content	0	0	100
(3) Segregation	0	0	100
(4) Delivery rate	0	40	60
(5) Breakdown of equipment	20	80	0

C. Revolving Drum Trucks

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	0	0	100
(2) Loss of air content	0	0	100
(3) Segregation	0	0	100
(4) Delivery rate	0	100	0
(5) Breakdown of equipment	0	0	100

D. Open-Top Truck Bodies

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	0	0	100
(2) Loss of air content	0	0	100
(3) Segregation	0	0	100
(4) Delivery rate	0	20	80
(5) Breakdown of equipment	0	0	100

E. Pump

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	0	0	100
(2) Loss of air content	0	0	100

Table 2 (Continued)

	% OFTEN	% OCCASIONALLY	% SELDOM
(3) Segregation	0	0	100
(4) Delivery rate	0	0	100
(5) Breakdown of equipment	0	0	100

4. **PROBLEMS RELATING TO CONSOLIDATION**

	OFTEN	OCCASIONALLY	SELDOM
A. Inadequate Vibration			
(1) Undersized vibrator	0	0	100
(2) Poorly maintained vibrator	0	40	60
(3) Improper spacing of insertions	0	50	50
(4) Inadequate duration of insertions	0	60	40
(5) Failure to penetrate into previous layer	0	60	40
(6) Wrong position relative to form	0	25	75
(7) Low slump	25	50	25
(8) Segregation	0	25	75
B. Overvibration			
(1) Oversized vibrator	0	0	100
(2) Improper procedures	0	25	75
(3) High slump	0	0	100
C. Resulting Imperfections			
(1) Honeycomb	0	100	0
(2) Excessive air voids	0	0	100
(3) Layer lines	0	50	50
(4) Form streaking	0	0	100

Table 2 (Concluded)

	% OFTEN	% OCCASIONALLY	% SELDOM
(5) Aggregate transparency	0	0	100
(6) Excessive form deflection	0	25	75
(7) Excessive loss of entrained air	0	0	100
(8) Cold joints	0	25	75

5. GENERAL

A. Surface Defects Appear to Result because of:

	OFTEN	OCCASIONALLY	SELDOM
(1) Design of members	0	50	50
(2) Improper formwork	0	50	50
(3) Construction conditions	0	0	100
(4) Properties of fresh concrete	0	75	25
(5) Placement procedures	0	25	75
(6) Consolidation procedures	0	67	33

B. Workability Problems Appear to Result because of:

(1) Excessive variation in concrete materials	0	50	50
(2) Poor mixture proportions	0	50	50
(3) Failure to adjust mixture proportions properly	25	25	50
(4) Improper batching/mixing equipment/procedures	0	0	100
(5) Improper transporting equipment/procedures	0	0	100
(6) Improper placing equipment/procedures	0	0	100
(7) Improper consolidation equipment/procedures	0	25	75

Table 3
Significant Complaint Areas Identified in Survey[1]

1. COMPLAINTS RELATING TO MATERIALS		
A. Handling and Storage		
(3) Aggregates	Corps	
B. Uniformity and/or Meeting Specifications		
(2) Pozzolan		Contractor
(3) Aggregates	Corps	Contractor
2. COMPLAINTS RELATING TO MIXTURE PROPORTIONS		
A. CE Proportioned Mixtures		
(1) Recommended mixture proportions require major adjustments when taken from laboratory to field	Corps	
(a) Adjustments were necessary to correct deficiencies in:		
Slump	Corps	Contractor
Air Content	Corps	
(2) Recommended mixture proportions require major adjustments during the course of a job		
(a) Adjustments were necessary to correct deficiencies in:		
Slump	Corps	Contractor
(b) Adjustments were necessary because of a change in these materials:		
Aggregates	Corps	Contractor
3. COMPLAINTS RELATING TO TRANSPORTING AND PLACING		
A. Bucket		
(4) Delivery rate	Corps	

[1] Items are identified by numbers and letters that correspond to items in the survey.

Table 3 (Continued)

B. Conveyor		
(3) Segregation	Corps	
(5) Breakdown of equipment	Corps	Contractor
C. Revolving Drum Trucks		
(1) Slump loss	Corps	
(4) Delivery rate		Contractor
D. Open-Top Truck Bodies		
(3) Segregation	Corps	
E. Pump		
(1) Slump loss	Corps	
4. COMPLAINTS RELATING TO CONSOLIDATION		
A. Inadequate Vibration		
(2) Poorly maintained vibrator	Corps	
(3) Improper spacing of insertions	Corps	
(4) Inadequate duration of insertions	Corps	
(5) Failure to penetrate into previous layer	Corps	
(6) Wrong position relative to form	Corps	
(7) Low slump		Contractor
C. Resulting Imperfections		
(1) Honeycomb	Corps	Contractor
(2) Excessive air voids	Corps	
5. GENERAL		
A. Surface Defects Appear to Result because of:		
(2) Improper formwork	Corps	
(4) Properties of fresh concrete		Contractor

Table 3 (Concluded)

(5) Placement procedures	Corps	
(6) Consolidation procedures	Corps	Contractor
B. Workability Complaints Appear to Result because of:		
(3) Failure to adjust mixture proportions properly	Corps	
(5) Improper transporting equipment/procedures	Corps	
(6) Improper placing equipment procedures	Corps	
(7) Improper consolidation equipment procedures	Corps	

Appendix A
Survey to Determine the Extent of Mass Concrete Workability Complaints Throughout the Corps of Engineers

1. PROBLEMS RELATING TO MATERIALS

A. Handling and Storage

	OFTEN	OCCASIONALLY	SELDOM
(1) Cement	___	___	___
(2) Pozzolan	___	___	___
(3) Aggregates	___	___	___
(4) Admixture	___	___	___

B. Uniformity and/or Meeting Specifications

	OFTEN	OCCASIONALLY	SELDOM
(1) Cement	___	___	___
(2) Pozzolan	___	___	___
(3) Aggregates	___	___	___
(4) Admixtures	___	___	___
(5) Steel reinforcement	___	___	___
(6) Curing compounds	___	___	___
(7) Joint materials	___	___	___

2. PROBLEMS RELATING TO MIXTURE PROPORTIONS

A. CE Proportioned Mixtures

	OFTEN	OCCASIONALLY	SELDOM
(1) Recommended mixture proportions require major adjustments when taken from laboratory to field	___	___	___
(a) Adjustments were necessary to correct deficiencies in:			
Slump	___	___	___
Air content	___	___	___
Segregation	___	___	___
Strength	___	___	___

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	OFTEN	OCCASIONALLY	SELDOM
(b) Adjustments were necessary because of a change in materials from laboratory to field	___	___	___
(2) Recommended mixture proportions require major adjustments during the course of a job	___	___	___
(a) Adjustments were necessary to correct deficiencies in:			
Slump	___	___	___
Air content	___	___	___
Segregation	___	___	___
Strength	___	___	___
(b) Adjustments were necessary because of a change in these materials:			
Cement	___	___	___
Pozzolan	___	___	___
Aggregates	___	___	___
Admixtures	___	___	___

3. PROBLEMS RELATING TO TRANSPORTING AND PLACING

A. Bucket

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	___	___	___
(2) Loss of air content	___	___	___
(3) Segregation	___	___	___
(4) Delivery rate	___	___	___
(5) Breakdown of equipment	___	___	___

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B. Conveyor

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	___	___	___
(2) Loss of air content	___	___	___
(3) Segregation	___	___	___
(4) Delivery rate	___	___	___
(5) Breakdown of equipment	___	___	___

C. Revolving Drum Trucks

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	___	___	___
(2) Loss of air content	___	___	___
(3) Segregation	___	___	___
(4) Delivery rate	___	___	___
(5) Breakdown of equipment	___	___	___

D. Open-Top Truck Bodies

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	___	___	___
(2) Loss of air content	___	___	___
(3) Segregation	___	___	___
(4) Delivery rate	___	___	___
(5) Breakdown of equipment	___	___	___

E. Pump

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	___	___	___
(2) Loss of air content	___	___	___

	OFTEN	OCCASIONALLY	SELDOM
(3) Segregation	___	___	___
(4) Delivery rate	___	___	___
(5) Breakdown of equipment	___	___	___

4. PROBLEMS RELATING TO CONSOLIDATION

A. Inadequate Vibration

	OFTEN	OCCASIONALLY	SELDOM
(1) Undersized vibrator	___	___	___
(2) Poorly maintained vibrator	___	___	___
(3) Improper spacing of insertions	___	___	___
(4) Inadequate duration of insertions	___	___	___
(5) Failure to penetrate into previous layer	___	___	___
(6) Wrong position relative to form	___	___	___
(7) Low slump	___	___	___
(8) Segregation	___	___	___

B. Overvibration

(1) Oversized vibrator	___	___	___
(2) Improper procedures	___	___	___
(3) High slump	___	___	___

C. Resulting Imperfections

(1) Honeycomb	___	___	___
(2) Excessive air voids	___	___	___
(3) Layer lines	___	___	___
(4) Form streaking	___	___	___
(5) Aggregate transparency	___	___	___

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	OFTEN	OCCASIONALLY	SELDOM
(6) Excessive form deflection	___	___	___
(7) Excessive loss of entrained air	___	___	___
(8) Cold joints	___	___	___

5. GENERAL

A. Surface Defects Appear to Result because of:

	OFTEN	OCCASIONALLY	SELDOM
(1) Design of members	___	___	___
(2) Improper formwork	___	___	___
(3) Construction conditions	___	___	___
(4) Properties of fresh concrete	___	___	___
(5) Placement procedures	___	___	___
(6) Consolidation procedures	___	___	___

B. Workability Problems Appear to Result because of:

(1) Excessive variation in concrete materials	___	___	___
(2) Poor mixture proportions	___	___	___
(3) Failure to adjust mixture proportions properly	___	___	___
(4) Improper batching/mixing equipment/procedures	___	___	___
(5) Improper transporting equipment/procedures	___	___	___
(6) Improper placing equipment/procedures	___	___	___
(7) Improper consolidation equipment/procedures	___	___	___

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6. PROVIDE A DETAILED DESCRIPTION OF SIGNIFICANT PROBLEMS IN THE SPACE BELOW. IF KNOWN, THE SOURCE OF THE PROBLEM AND THE CORRECTIVE ACTION TAKEN SHOULD ALSO BE GIVEN. PLEASE IDENTIFY THE PROBLEM WITH ONE OF THE CATEGORIES LISTED IN THE SURVEY.

Appendix B
Number of Responses from Corps of Engineers Staff Members

1. PROBLEMS RELATING TO MATERIALS

A. *Handling and Storage*

	OFTEN	OCCASIONALLY	SELDOM
(1) Cement	1	7	26
(2) Pozzolan	0	8	26
(3) Aggregates	6	23	4
(4) Admixture	3	8	22

B. Uniformity and/or Meeting Specifications

	OFTEN	OCCASIONALLY	SELDOM
(1) Cement	0	9	24
(2) Pozzolan	4	12	18
(3) Aggregates	6	24	4
(4) Admixtures	0	11	22
(5) Steel reinforcement	1	3	30
(6) Curing compounds	4	10	18
(7) Joint materials	1	10	21

2. PROBLEMS RELATING TO MIXTURE PROPORTIONS

A. CE Proportioned Mixtures

	OFTEN	OCCASIONALLY	SELDOM
(1) Recommended mixture proportions require major adjustments when taken from laboratory to field	5	16	10
(a) Adjustments were necessary to correct deficiencies in:			
Slump	8	15	7
Air content	5	16	10
Segregation	1	15	15
Strength	0	8	21

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	OFTEN	OCCASIONALLY	SELDOM
(b) Adjustments were necessary because of a change in materials from laboratory to field	2	16	13
(2) Recommended mixture proportions require major adjustments during the course of a job	2	10	17
(a) Adjustments were necessary to correct deficiencies in:			
Slump	6	16	8
Air content	6	12	12
Segregation	1	17	13
Strength	1	9	21
(b) Adjustments were necessary because of a change in these materials:			
Cement	0	11	17
Pozzolan	2	11	15
Aggregates	5	20	4
Admixtures	1	10	18

3. PROBLEMS RELATING TO TRANSPORTING AND PLACING

A. Bucket

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	2	15	16
(2) Loss of air content	3	14	18
(3) Segregation	0	15	18
(4) Delivery rate	4	21	9
(5) Breakdown of equipment	1	19	14

B. Conveyor

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	6	13	12
(2) Loss of air content	9	10	12
(3) Segregation	6	17	8
(4) Delivery rate	1	18	12
(5) Breakdown of equipment	4	24	4

C. Revolving Drum Trucks

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	5	19	8
(2) Loss of air content	3	13	16
(3) Segregation	0	9	23
(4) Delivery rate	2	18	12
(5) Breakdown of equipment	0	20	13

D. Open-Top Truck Bodies

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	3	13	12
(2) Loss of air content	1	10	17
(3) Segregation	2	16	8
(4) Delivery rate	0	10	19
(5) Breakdown of equipment	0	11	18

E. Pump

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	8	14	8
(2) Loss of air content	7	11	11

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		OFTEN	OCCASIONALLY	SELDOM
(3)	Segregation	1	12	17
(4)	Delivery rate	1	14	15
(5)	Breakdown of equipment	4	15	11

4. PROBLEMS RELATING TO CONSOLIDATION

A. Inadequate Vibration

		OFTEN	OCCASIONALLY	SELDOM
(1)	Undersized vibrator	5	16	13
(2)	Poorly maintained vibrator	12	16	6
(3)	Improper spacing of insertions	20	10	4
(4)	Inadequate duration of insertions	12	12	11
(5)	Failure to penetrate into previous layer	14	13	7
(6)	Wrong position relative to form	12	13	8
(7)	Low slump	2	20	11
(8)	Segregation	1	15	15

B. Overvibration

		OFTEN	OCCASIONALLY	SELDOM
(1)	Oversized vibrator	2	6	26
(2)	Improper procedures	11	7	16
(3)	High slump	3	13	18

C. Resulting Imperfections

		OFTEN	OCCASIONALLY	SELDOM
(1)	Honeycomb	11	18	5
(2)	Excessive air voids	11	17	7
(3)	Layer lines	5	16	12
(4)	Form streaking	2	18	13
(5)	Aggregate transparency	0	11	18

		OFTEN	OCCASIONALLY	SELDOM
(6)	Excessive form deflection	4	20	9
(7)	Excessive loss of entrained air	0	9	24
(8)	Cold joints	0	17	14

5. GENERAL

A. Surface Defects Appear to Result because of:

		OFTEN	OCCASIONALLY	SELDOM
(1)	Design of members	1	7	24
(2)	Improper formwork	4	23	5
(3)	Construction conditions	2	17	12
(4)	Properties of fresh concrete	1	9	21
(5)	Placement procedures	11	16	5
(6)	Consolidation procedures	13	16	3

B. Workability Problems Appear to Result because of:

(1)	Excessive variation in concrete materials	3	17	12
(2)	Poor mixture proportions	5	11	17
(3)	Failure to adjust mixture proportions properly	9	13	10
(4)	Improper batching/mixing equipment/procedures	3	15	14
(5)	Improper transporting equipment/procedures	3	20	9
(6)	Improper placing equipment/procedures	6	19	7
(7)	Improper consolidation equipment/procedures	11	17	5

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Appendix C
Number of Responses from Contractor Staff Members

1. PROBLEMS RELATING TO MATERIALS

A. Handling and Storage

	OFTEN	OCCASIONALLY	SELDOM
(1) Cement	0	1	4
(2) Pozzolan	0	0	5
(3) Aggregates	0	3	2
(4) Admixture	0	0	5

B. Uniformity and/or Meeting Specifications

	OFTEN	OCCASIONALLY	SELDOM
(1) Cement	0	0	5
(2) Pozzolan	0	4	1
(3) Aggregates	1	4	0
(4) Admixtures	0	0	5
(5) Steel reinforcement	0	0	5
(6) Curing compounds	0	0	5
(7) Joint materials	0	0	5

2. PROBLEMS RELATING TO MIXTURE PROPORTIONS

A. CE Proportioned Mixtures

	OFTEN	OCCASIONALLY	SELDOM
(1) Recommended mixture proportions require major adjustments when taken from laboratory to field	0	2	1
(a) Adjustments were necessary to correct deficiencies in:			
Slump	3	1	0
Air content	0	2	2
Segregation	0	0	4
Strength	0	0	4

	OFTEN	OCCASIONALLY	SELDOM
(b) Adjustments were necessary because of a change in materials from laboratory to field	0	1	3
(2) Recommended mixture proportions require major Adjustments during the course of a job	1	1	2
(a) Adjustments were necessary to correct deficiencies in:			
Slump	2	2	0
Air content	0	2	2
Segregation	0	0	3
Strength	0	0	3
(b) Adjustments were necessary because of a change in these materials:			
Cement	0	0	4
Pozzolan	0	0	4
Aggregates	0	3	1
Admixtures	0	1	4

3. PROBLEMS RELATING TO TRANSPORTING AND PLACING

A. Bucket

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	0	0	4
(2) Loss of air content	0	0	4
(3) Segregation	0	1	3
(4) Delivery rate	0	1	4
(5) Breakdown of equipment	1	0	4

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B. Conveyor

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	0	0	4
(2) Loss of air content	0	0	4
(3) Segregation	0	0	5
(4) Delivery rate	0	2	3
(5) Breakdown of equipment	1	4	0

C. Revolving Drum Trucks

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	0	0	1
(2) Loss of air content	0	0	1
(3) Segregation	0	0	1
(4) Delivery rate	0	1	0
(5) Breakdown of equipment	0	0	1

D. Open-Top Truck Bodies

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	0	0	4
(2) Loss of air content	0	0	4
(3) Segregation	0	0	4
(4) Delivery rate	0	1	4
(5) Breakdown of equipment	0	0	5

E. Pump

	OFTEN	OCCASIONALLY	SELDOM
(1) Slump loss	0	0	1
(2) Loss of air content	0	0	1

		OFTEN	OCCASIONALLY	SELDOM
(3)	Segregation	0	0	1
(4)	Delivery rate	0	0	1
(5)	Breakdown of equipment	0	0	1

4. **PROBLEMS RELATING TO CONSOLIDATION**

A. Inadequate Vibration

		OFTEN	OCCASIONALLY	SELDOM
(1)	Undersized vibrator	0	0	4
(2)	Poorly maintained vibrator	0	2	3
(3)	Improper spacing of insertions	0	2	2
(4)	Inadequate duration of insertions	0	3	2
(5)	Failure to penetrate into previous layer	0	3	2
(6)	Wrong position relative to form	0	1	3
(7)	Low slump	1	2	1
(8)	Segregation	0	1	3

B. Overvibration

(1)	Oversized vibrator	0	0	4
(2)	Improper procedures	0	1	3
(3)	High slump	0	0	3

C. Resulting Imperfections

(1)	Honeycomb	0	5	0
(2)	Excessive air voids	0	0	4
(3)	Layer lines	0	2	2
(4)	Form streaking	0	0	4
(5)	Aggregate transparency	0	0	4

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		OFTEN	OCCASIONALLY	SELDOM
(6)	Excessive form deflection	0	1	3
(7)	Excessive loss of entrained air	0	0	4
(8)	Cold joints	0	1	3

5. GENERAL

A. Surface Defects Appear to Result because of:

		OFTEN	OCCASIONALLY	SELDOM
(1)	Design of members	0	2	2
(2)	Improper formwork	0	2	2
(3)	Construction conditions	0	0	4
(4)	Properties of fresh concrete	0	3	1
(5)	Placement procedures	0	1	3
(6)	Consolidation procedures	0	2	1

B. Workability Problems Appear to Result because of:

(1)	Excessive variation in concrete materials	0	2	2
(2)	Poor mixture proportions	0	2	2
(3)	Failure to adjust mixture proportions properly	1	1	2
(4)	Improper batching/mixing equipment/procedures	0	0	4
(5)	Improper transporting equipment/procedures	0	0	4
(6)	Improper placing equipment/procedures	0	0	4
(7)	Improper consolidation equipment/procedures	0	1	3

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Appendix D
Detailed Descriptions of Complaints Encountered by Corps of Engineers Staff Members and Possible Solutions Offered

6. PROVIDE A DETAILED DESCRIPTION OF SIGNIFICANT PROBLEMS IN THE SPACE BELOW. IF KNOWN, THE SOURCE OF THE PROBLEM AND THE CORRECTIVE ACTION TAKEN SHOULD ALSO BE GIVEN. PLEASE IDENTIFY THE PROBLEM WITH ONE OF THE CATEGORIES LISTED FOR THE SURVEY.

Respondent No. 1

1B--Materials--Uniformity and/or meeting specifications

Occasional problems with nonuniformity of fly ash, especially from certain plants.

Occasional problems arise when a cement manufacturer makes a change in his materials or procedures and the change affects the concrete strength. The cement does not go out of spec. This happened when Type IP was changed from "summer" formulation to "winter" formulation and vice versa (more and less pozzolan in the mix).

Other problems arose when a Type II (MH) manufacturer changed the cement to a slightly lower heat of hydration; concrete strengths suddenly went down.

Solutions

Faster testing and reporting.

On large mass concrete jobs, some sort of notification process that a change will be made.

4A and 4C--Consolidation--Inadequate vibrations and resulting in perfections

Many contractor personnel are not familiar with consolidating lean mass concrete. Some of this is overcome as experience is gained. Contractors themselves do not understand that more time and effort are required to place and consolidate mass concrete when compared to structural concrete. When the unexpected slow production occurs, along with complaints from the placing crews, claims are filed.

Solution (partially anyway!)

Closer attention to the mix design providing more workability.

Mix design personnel (WES) and engineering division personnel work with construction early, soon after construction starts. Construction people usually do not call for help until all else fails.

Meetings with contractor superintendent and foreman before and during early construction. Participation in "training classes" for vibrator operators, if possible. It may be wise to require these meetings and training (preconstruction) in the specifications.

Respondent No. 2

4—Consolidation

Contractors have insufficient numbers of vibrators, and they very poorly maintain those that are in service.

Conveyor used to transport concrete causes some segregation problems primarily due to the tremie pipe being sent on a slope.

Suggestion for handling and storage of materials

More emphasis should be placed in the specifications on stockpiling of coarse aggregates; unless handled properly, there always comes a point in each project where the materials are out of gradation.

Suggestion for open-top truck bodies for transporting and placing

"Agitator" trucks - These bodies will not agitate 75-mm (3-in.) concrete as delivered to a project. They must be modified by shortening the agitating blades which results in some segregation in the trucks. Specifications should say that before this type of transportation system is approved, it must be demonstrated that they will perform properly.

Respondent No. 3

COMMENTS: Workability of Concrete for Locks and Dams

A. Nearly every time Contractors complain about the workability of Government-furnished mix proportions, it is because they are not following proper batching, mixing, transporting, placing, and/or consolidation procedures.

B. However, sometimes our mix proportions allow little room for deviation from the ideal procedures. Unless proper procedures are performed at all times by the Contractor, difficulty in obtaining the desired end often results. Because proper procedures are not followed consistently and some of our mixes demand strict compliance, we are left with excessive deficiencies in the end product. This is usually when the Contractor attacks our mixes as unworkable.

C. We often design mix proportions for mass concrete and then use them in structures that are not mass concrete. This increases the effort required to properly batch, mix, and place the concrete and actually requires more strict adherence to proper procedures than should be necessary.

D. In my experience (on concrete mixes for locks and dams), when we provide mix proportions having 37.5-mm (1-1/2-in.) maximum size coarse aggregate having a mortar (paste, fine aggregate, and entrained air) content of less than about 14 cu ft/cu yd, more than normal work effort is necessary to obtain the desired results. This is based on the following:

Paste content (cement, water, entrained air) = 6.8 cu ft

Fine aggregate (CA:FA, 65:35 or 35% FA)* = 7.07 cu ft

*If CA is crushed stone, this may be increased by about 2%.

E. The method of placing the concrete may also affect the mortar content quantity. I personally think that concrete with the mortar content mentioned above can be placed using any present day state-of-the-art equipment and procedures. If problems occur in the field, field adjustments of the mix can be made when needed.

F. I recommend that concrete mixes containing slightly more mortar be developed for structures like locks and dams. I believe this would result in fewer complaints by Contractors concerning workability and result in little or no reduction of quality.

Respondent No. 4

I have not been involved much with problems of workability unless the problem is due to improper specifications. As indicated by the checklist, there have been problems as noted, but none have been significant except for the slump loss problems. The problem was resolved by not using the water-reducing admixture.

Respondent No. 5

The single and most frequent problem associated with consistency of the mixes was fine aggregate free moisture. Variability of free moisture was considerable even when fine aggregate stockpile was given 2-3 days to stabilize and resulted in continual testing/adjusting of fine aggregate free moisture. This variability also made mix proportion adjustments very difficult to "fine tune" and finalize.

Another problem was the 10-ft high forms. A small movement during placement of the first lift resulted in a magnified deflection of the upper half of the 10-ft form. Additional bracing and adjustment to forms between lifts was required. In the same situation, if the first lift was on the high side of the allowed slump when placed, a small amount of shrinkage occurs and the resulting gap between the forms and the first lift had to be sealed before placing the second lift to prevent grout loss. Also, any movement in the forms during placement of second lift invariably led to grout loss, i.e. honeycomb. Additional bracing of forms was required to prevent this from occurring.

Respondent No. 6

Production/specification

Background. The fine aggregate used is manufactured sand. The process uses a dry classified, i.e. air separator. The plant produces a consistent product; however, it contains excessive fines, in the area of 11 to 12% (wet wash).

Problem. Neither the job specifications nor the guide specifications require a wash or even a control on the amount of -200 material in the fine aggregate. The fines were reduced to 6-8% (wash). Because of the separating process, no more fines could be removed without severely affecting the #30 - #100 sieves, i.e. forcing them outside the permissible limits, thereby resulting in a poorly graded material.

The excessive fines had a tendency to adhere to each other to form seemingly larger particles when the moisture content rose above 2 to 3%. Sieving action would not break down these "balls." However, when the fines were reduced, this phenomena was reduced drastically. It should also be noted that the excessive fines would blank out the screens without regard to extended sieving time. Each sample required additional hand-sieving to properly complete analysis. Even with reduced fines, sieving is required.

Solution. Incorporate American Society for Testing and Materials (ASTM) C 33 (CRD-C-133)[1] (deleterious material) into the guide specification when utilizing manufactured sand, particularly where a dry process is selected.

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[1] ASTM. (1991). "Standard specification for concrete aggregates," Designation: C 33-90, *1991 annual book of ASTM standards*. Philadelphia, PA. The CRD-C equivalent in parentheses is from *Handbook for concrete and cement*, U.S. Army Engineer Waterways Experiment Station, 1949, Vicksburg, MS.

Respondent No. 7

On our current project, the Contractor is using crushed limestone as his fine aggregate for the concrete. In running grading tests, we noticed that there was a significant difference in the apparent grading between a conventional sieve analysis (ASTM C 136 (CRD-C 103))[1] and a 75 μm (No. 200) wash test, as much as 5%. This difference was especially noticeable if the material had been wetted at least one time prior to drying the sample for the sieve analysis. Apparently there is some low-strength bonding taking place when the material is wetted [and] dried because the wash test showed that there was a significant amount of 150 μm (No. 100) and 75 μm (No. 200) material adhering to the layer particles that was not being separated during the course of performing the specified sieve analysis (ASTM C 136).

We have worked around this problem to a large extent by using a very aggressive shaking method to try to break down these material bonds. This is a much greater effort than we have needed to use in the past for natural sands and exceeds the efforts outlined in ASTM C 136 (CRD-C 103). The problem is that personnel not familiar with this phenomenon may not recognize the need to use any different shaking technique when using crushed limestone as opposed to using natural sand. As a result, the limestone material may seem to be coarser than it actually is. Somehow, testing personnel should be alerted to this problem, or the specifications should be changed to address this situation.

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[1] ASTM. (1991). "Standard method for sieve analysis of fine and coarse aggregates," Designation: C 136-84a, *1991 annual book of ASTM standards*. Philadelphia, PA. The CRD-C equivalent in parentheses is from the *Handbook for concrete and cement*, U.S. Army Engineer Waterways Experiment Station, 1949, Vicksburg, MS.

Respondent No. 8

Materials

1B. Aggregates. Generally speaking, it is more difficult to obtain manufactured fine aggregate which meets the somewhat strict requirements of the Corps guide specifications than to obtain natural fine aggregate meeting these same specifications.

Transporting and placing

3B. Conveyor equipment. Generally speaking, conveyor equipment is more susceptible to breakdowns than buckets. Also, segregation is more likely to occur due to the extra handling. Conveyor equipment should be of the proper size and capacity to handle large size aggregate concrete 75-mm (3 in. or larger). Also delivery rate tends to be less than with buckets for mass concrete.

Consolidation

4A. Inadequate vibration. Regarding improper spacing and failure to penetrate previous layer, education of inspectors and contractor personnel is the answer.

General

5B. Mixture proportions are usually determined by strength requirements and slump requirements (plus air). While slump is an aid in determining workability, it is not the complete answer to a workable concrete. The labs should conduct workability tests and compactibility tests of their design mixes if practical.

Respondent No. 9

A. Accumulative weight batchers should not be permitted under any circumstances.

B. The use of limestone coarse aggregate should be encouraged.

C. Better protection of sand piles should be required to prevent major fluctuation of sand moisture.

D. The Corps of Engineers PROSPECT course should be geared toward field situations.

E. The use of manufactured sand is a major cause of problems.

F. Mix designs should be adjusted to better handle changes in field conditions.

Respondent No. 10

5B(7)
Improper consolidation equipment and procedures

Corrective action: Vibrators with too low RPM and improper dryers on air lines

Respondent No. 11

A. All mass concrete, civil and military, should be designed and controlled by the Corps of Engineers because often a problem arises due to mixes that have not been properly designed by the contractor or the supplier. Also, after the Corps of Engineers has approved a contractor's or supplier's design mix, they will make adjustments to the mix, mainly to increase strength in order to strip forms at an early age, which can cause a heat of hydration problem that they do not recognize or understand.

B. Another problem when contractor furnishes the mix design and performs plant control is that coarse aggregate free moisture corrections are not made and additional cement is added to the mix to assure that design strength is obtained.

C. Temperature of concrete is not taken very seriously. More emphasis should be stressed pertaining to temperature.

D. Grading of fine and coarse aggregates are not constantly controlled.

E. The number of vibrators are inadequate for the concrete mix that is to be vibrated.

Respondent No. 12

The major problem with concrete construction today is the lack of care or concern of the individuals involved.

Poor techniques generally occur after the mixing of the concrete mixtures.

Transportation, placing, consolidation, finishing, and curing procedures are where a large percentage of problems are located.

The materials, batching, mixing, and control of mixtures prior to placement is generally considered to be more important than other things.

Mixes with higher slumps, etc. are what appear to be in demand by the contractors. Supposedly, this will give them a better product with reduced labor costs.

Respondent No. 13

5-B(6)
Workability problems

Segregation that occurs at the end of a conveyor belt results in rock pockets and poorly consolidated concrete. The height of the drop and size of the aggregates make a difference.

Respondent No. 14

1-A
Materials--Handling and storage

Created through loading/transporting from quarry and methods of stockpiling at job sites.

2-A(1)
CE Proportional mixtures when taken from
laboratory to field and during course of a job

Always requires adjustments - I don't recall making major changes.

3-A(1)
Transporting and placing--bucket and slump loss

Usually due to long hauls from plant to placement or long waits before placing.

3-A(3)
Bucket and segregation

Usually occurs with larger size aggregate 75-mm (3 in. or larger).

3-A(4) & (5)
Bucket and delivery rate and breakdown of equipment

Haul distance too long or maybe not enough haul units.

3-B
Conveyor

Conveyor problems seem to be less with short haul open-top trucks or conveyor from plant to placement regarding loss of slump, air, and segregation.

3-C
Revolving drum trucks

Revolving drum truck problems are usually a result of long distances between plant and placement.

5-B(1) and (2)
Workability problems

Usually a plant problem (excessive variation in concrete materials and poor mixture proportions).

Respondent No. 15

4-C(1), 5-A(3)
Consolidation and construction condition problems: corrective action

Honeycomb and rock pockets around congested areas of re-steel and embedded items. Prime example is the area around floating mooring bits in lock walls. Re-steel design and support steel often make the area so congested that the placement of concrete and proper vibration of concrete is very difficult, often resulting in rock pockets and joint lines. Corrective action may require a look at the design in these areas.

4A(2), (3), (5), and (6); 4B(2); 4C(1) and (3)
Consolidation problems due to inadequate vibration,
overvibration, and resulting imperfections, correction action

Problems relating to consolidation of concrete, which is a prime concern of QA organizations, often result in rock pockets, joint lines, poor surface appearance, form movement, and poor quality concrete. Corrective action can fall into three areas of responsibility: (1) QA, (2) QC, and (3) union labor. Training of QA and QC will help to some extent, but the major training needs to be conducted at the union level. Union labor is convinced that they know everything about concrete to include consolidation and proper placement, and QA and QC know nothing and should not tell union labor how to place and consolidate concrete.

Respondent No. 16

This District has had no major mass concrete construction projects since the 1977-79 time frame. Detailed descriptions of significant problems cannot be provided. Very few people remain with mass concrete experience.

Respondent No. 17

The most general and consistent problems which I have noted over many jobs has always been improper construction techniques and inexperienced personnel. When and if these factors are resolved, many of the apparent mix design, etc. problems seem to disappear.

One significant problem which has occurred on the last several jobs I have been on has been an apparent slump and air content loss with time. These losses did not appear to be related to mix design, equipment, or procedures but were more materials oriented; i.e., admixture(s) not compatible with cementitious materials or there was a false set type phenomenon. These type problems are more troublesome when nonagitating transportation equipment is used.

Respondent No. 18

This problem is identified with category 5 of the survey, and in particular 5B. Contractors, including their suppliers, sometimes lapse in their responsibilities. Gradations and moisture contents slip outside specified limits, cement will occasionally be used to handle materials, equipment breaks down, people are not trained properly, and many other problems.

We must recognize that we work in the real world. We are working with real life problems that transcend "the book." We deal with mechanical devices that by their nature require maintenance and repair, we deal with adverse weather, we deal with real people that are both reasonable and unreasonable, and we deal with specifications that occasionally fail to take these and similar items into account.

The office and laboratory in which the concrete mixes are designed, tested, and refined are far from the realities of the way things are when the concrete is produced and placed on the project. Mix designs appear to be more sophisticated and refined to the "edge" or the "limits" in order to save money on the more expensive components of the mix, i.e. cement. When these textbook designs encounter actual field conditions, problems are encountered that result in an allegation by the Contractor of workability. Too often the designers take offense and the result is an adversarial relationship with the Resident Engineer and staff in the middle.

When the contractor is required to spend money excessively to form, place, vibrate, patch, and repair a concrete mix that is on the "limits" of workability, these costs will be eventually transferred back to the Government in the form of higher bids. Claims result and more often than not are settled in the Contractor's favor.

Laboratory designed concrete mix designs are harsh, which means they lack paste or mortar, and therefore create problems in workability. Even though the strength may be in a concrete mix, the amount of mortar is borderline to cover the aggregate and fill the voids. It must be recognized that lack of mortar to adequately fill the voids and lubricate the mix may be more than the theoretical required for just the voids. Problems with workability create problems with the efficiency of the concrete operation.

The reduction in the amount of cementitious materials to reduce the cost of concrete produces a lean mix which is harsh and hard to work. Contractors have come to realize this and pad their bids for inefficiency and future claims. A mix design which would have more cementitious materials to not only fill the voids but also lubricate the mix would be more workable and increase efficiency. In the long run, concrete prices would be reduced and the amount of claims would be reduced.

Solution: Design concrete mixes with more mortar. Slump, air content, etc. can remain the same.

Respondent No. 19

Need to specify minimum cement content because you can get strength by using water reducers and certain high-quality aggregates. However, the mix is lean and will not finish without adding water.

High-range water reducing admixtures should be blown into the mixer with a portion of the water at the end of adding materials or the mixer should be shut down, and they should be hand sprayed on the surface of the mix. They give many problems when a carpenter foreman dumps them in the end of the mixer with a bucket.

Slump, air, etc. should be taken at the outlet end of the pump hose.

Respondent No. 20

Most problems related to mass concrete workability, placement, and conveyance are the direct result of inexperience of the contractor's construction placement personnel and quality control staff, as well as the CE quality assurance staff. Usually, construction personnel (both contractor and CE) are not fully aware of specification requirements, appropriate concrete construction practice, or test procedures. The Corps of Engineers relies heavily on contractor quality control; however, contractor QC personnel often has little or no field experience with mass concrete. The number and experience level of many Corps of Engineers project QA personnel are such that many construction-related problems are not even recognized as problems.

There is a general lack of enforcement of construction specifications with respect to quality control measures such as stockpiling aggregates, materials testing, placement procedures, uniformity tests, hot and cold weather concreting procedures, etc. Too much emphasis is given to meeting scheduled deadlines and, as a result, the quality of product is jeopardized. Often, specifications are not enforced as a result of lack of clarity in specifications, reluctance to introduce delays to construction, unwillingness by the contractor and contractor QC to comply, or a fear of introducing a claim.

Often there is animosity between construction and engineering personnel within the Corps, as well as between the contractor and CE project staff. This hostility is counterproductive and usually effects job quality.

Respondent No. 21

Quality is a function of field conditions. Harsh mix designs have been found to be difficult to consolidate, difficult to transport, difficult to dump, difficult to handle, difficult to finish in stretch cracks, in post holes, in pump breakdowns, in pump-line stoppages, in conveyor difficulties, and in increased cracking following the reinforcing alignment. Harsh mix designs are also more sensitive to weather conditions. In order to ensure a quality product, field conditions have to be considered. The following paragraphs address some of the problems encountered in my experience.

A. Quick stiffening: During the construction of a lock and dam, the initial mix designs were found to experience a 1 to 1-1/2-in. loss in slump 30 min. after mixing was completed. WES determined that the combination of three materials (water, cements, and WRA) were not compatible. The problem was reduced significantly by leaving the WRA out of the mix. This also resulted in a mixture requiring less water and cement than that with the WRA.

B. Premature surface stiffening: Due to the same problem as described above, the surface of the placement would take a set prior to the underlying concrete. The surface would stiffen sufficiently to support workers without allowing them to sink into the concrete, but the underlying concrete would remain in a soft plastic state. People walking across these surfaces would cause wave undulations to occur resulting in surface cracking which would not self heal. This would not occur if personnel were kept off the surface until sufficient curing had occurred.

C. Discontinuity at horizontal construction joints: At two projects, discontinuity at horizontal construction joints was a problem prior to adjustments in mix designs or to other corrective measures. The mix designs seemed to be lacking in a sufficient quantity of free mortar to coat and bond to the surface of the previous placement. At one, this was resolved by placing a free flowing grout on the joint immediately prior to the concrete. At the other, the total amount of cements in the mix design was increased by the use of more fly ash which resolved the problem.

D. Honeycomb in formed surfaces: At both projects, much of the honeycomb resulted because workers were unable to insert the large 6-in. vibrators between the vertical reinforcing steel and the forms. The harsh mix designs are found to have vibration influence areas which are smaller than normally expected. The problem was resolved at one by the use of 2-in. vibrators next to the forms. At the other, the change in the mix design was significant to permit greater workability which increased the diameter size of the vibration influence area.

E. Voids around vertical reinforcing. Many times tall-standing, vertical reinforcing steel is pushed aside to pass buckets or personnel, to insert vibrators, is hit accidentally by placing equipment, or can be wiggled by workers grasping the steel. Harsh mix designs require good vibration in order to form

K. Contractor workability adjustments. Most contractors associate workability with the slump characteristic, and the slump characteristic with the free water in the mix. Although it is not entirely true that workability is a function of free water, free water is the item which is most frequently adjusted (and normally the only item the contractor will adjust) to stay within the contract slump range. Water content in a harsh mix versus a moderate mix has a much greater effect on the overall characteristics such as strength, durability, shrinkage, free air, particle segregation, and workability. Harsh mixes are much more sensitive to water adjustments than are moderate mixes. Increased water usually results in negative characteristics; therefore, it is not desirable. This is something that has been found to be very difficult to communicate convincingly to the contractor and his workers. This becomes especially difficult when the contractor has chosen means of transporting, handling, placing, and consolidating which do not lend themselves well to harsh mix designs. Low-bid contracts do not always permit the Government to take a hard stand, and the mix is usually adjusted to the field conditions and to the contractor conditions in order to prevent contractor claims, to keep the job on schedule, and to ensure a quality product.

L. Transverse cracks following horizontal steel in finished concrete surfaces. I have found that the cracks in the finished surfaces which follow the steel to be more prevalent in harsh mixes than in mixes which are richer in paste. These cracks are more prevalent in surfaces underlaid by bars of 1 in. and larger. Although I am not certain as to the reason for the increased cracks in the harsh mixes, I believe that they may be related to either a function of the strength-time relationship or a function of cement content versus elasticity in partially cured concrete. Apparently due to the higher thermal coefficient of steel, the steel imparts tension forces which the concrete is unable to withstand during the curing period.

M. Alligator cracks in finished concrete horizontal surfaces. Harsh mixes are most difficult to finish. Mixes which are border line on grout are very difficult to finish. Finishing becomes an extremely difficult and arduous task on hot days when the sun is quickly removing the surface moisture. On a harsh mix, finishers will always attempt to increase the ease with which surfaces are finished and the appearance of the finished surface. Free grout is a function of both items desired by the finisher. Normally, the only ingredient over which the finisher has control is the water. If not stopped by an inspector, the finisher will add water to the surface to produce a more workable grout. This water added to the surface will normally result in an excess water-cement ratio surface grout which will shrink considerably upon curing and drying. This shrinkage causes a pattern of numerous irregular surface cracking normally referred to as alligator cracks as a similarity to the pattern of cracks in an alligator skin.

Respondent No. 22

A. During the 1980's, we received claims from Contractors due to alleged lack of mass concrete workability on two projects. On both jobs, the Contractors used a Creter Crane from Ro-Teck to place the concrete with 3-in. max. size coarse aggregate.

B. The staffs consulted frequently during construction with the laboratory, the division, and the district concrete materials engineers and fine-tuned the various mass concrete mixes at both projects in an effort to work with the Contractor. Both Contractors persisted with complaints about workability and hired a concrete mix design consultant who supported the Contractors' claims.

C. The resident staff for both projects denied these workability claims, but several years after the construction was completed on each project, the claims were settled in combination with other project claims not related to concrete. The combination settlement made it unclear how much, if any, damages were paid to the Contractor due to workability claims.

D. Due to the nebulous aspects of adequate concrete workability, I believe the Corps will probably be hit with future mass concrete workability claims for Government mixes with 3-in. and larger coarse aggregate. It is likely that the word will spread among Contractor organizations that the Corps is vulnerable in this area because it comes down to the opinion of one expert against the opinion of another "expert."

Respondent No. 23

Government Mass Concrete Guide Specifications are too detailed and too long.

Government mandated QA/QC program does not provide as good a product as it should – especially for complicated major multipurpose projects.

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13. ABSTRACT *(Maximum 200 words)*

This report presents and discusses the results of a survey of Corps of Engineers (CE) Division and District staff members familiar with mass concrete construction to determine the extent of mass concrete workability complaints throughout the CE as well as the purported causes of the problems. CE Divisions and Districts having recent experience with mass concrete construction were solicited to provide input describing workability complaints.

The results of the survey indicate that while mass concrete mixtures can be harsh and difficult to work, many times the workability problems are the result of aggregates being out of specification requirements for grading or improper transporting, placing, or consolidating equipment or procedures. Almost one-half of the identified problem areas deal with consolidation equipment and procedures.

Recommendations are made to disseminate the results of the survey to other CE staff members, to require meeting or training sessions for contractor personnel involved with consolidating mass concrete, to investigate the feasibility of requiring a minimum mortar content for 37.5-mm (1-1/2-in.) nominal maximum size aggregate (NMSA) mass concrete, to investigate the feasibility of requiring a paste-mortar ratio for 37.5-mm (1-1/2-in.) NMSA and 75-mm (3-in.) NMSA mass concrete, and to investigate the feasibility of placing mass concrete at higher slumps.

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